EPRI

2022-004 BWR Vessel & Internals Project (BWRVIP)

(via e-mail)

January 20, 2022

Document Control Desk
U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Attention: Serita Sanders

Subject: Docket No. 99902016 – BWRVIP Response to BWRVIP-315 Draft Safety Evaluation

References:

1. Email from Joseph J. Holonich (NRC) to Wynter McGruder (EPRI) "Draft Safety Evaluation for BWRVIP-315," dated September 1, 2021 (BWRVIP Letter 2021-063A, NRC ADAMS Accession No. ML21105A038)

2. Meeting between the NRC staff and EPRI, "Closed Meeting to discuss the draft Safety Evaluation for BWRVIP-315," dated September 28, 2021 (NRC ADAMS Accession No. ML21256A060)

3. Letter from Nathan Palm (BWRVIP Program Manager) to Joseph J. Holonich (NRC) "Docket No. 99902016 – September 28, 2021 Closed Meeting with the NRC to discuss the draft Safety Evaluation for BWRVIP-315" dated September 22, 2021 (BWRVIP Letter 2021-069, NRC ADAMS Accession No. ML21266A227)

4. Letter from Tim Hanley (BWRVIP Chairman) to Joseph Holonich (NRC), "Transmittal of BWRVIP-315: BWR Vessel and Internals Project, Reactor Internals Aging Management Evaluation for Extended Operations," dated October 22, 2019 (BWRVIP Letter 2019-096, NRC ADAMS Accession No. ML19297G276)

5. Letter from Tim Hanley (BWRVIP Chairman) to Joseph Holonich (NRC), "BWRVIP Docket No. 99902016 – BWRVIP Response to BWRVIP-315 Request for Additional Information (RAIs)," dated February 15, 2021 (BWRVIP Letter 2021-015, NRC ADAMS Accession No. ML21047A085)

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6. Email from Joseph J. Holonich (NRC) to Wynter McGruder (EPRI), "Proprietary Information Withholding Determination for BWRVIP-315 RAI Response," dated March 12, 2021 (NRC ADAMS Accession No. ML21047A084)

7. Letter from Joseph J. Holonich (NRC) to Tim Hanley (BWRVIP Chairman), "Acceptance Review and Proprietary Determination for EPRI Topical Report, BWRVIP-315: BWR Vessel and Internals Project, Reactor Internals Aging Management Evaluation for Extended Operations," dated February 24, 2020. (BWRVIP Letter 2020-009B, NRC ADAMS Accession No. ML19296A008)

The NRC email referenced above (Reference 1) transmitted a draft NRC Safety Evaluation (SE) of the BWRVIP report entitled "BWRVIP-315: BWR Vessel and Internals Project, Reactor Internals Aging Management Evaluation for Extended Operations" to the BWRVIP and requested that the BWRVIP identify any proprietary information in the draft SE. The email also requested that the BWRVIP identify any factual errors or clarity concerns associated with the draft Safety Evaluation.

The BWRVIP met with the NRC in a closed meeting (Reference 2) to discuss the draft SE for BWRVIP-315, including the conditions and open item contained in the draft SE. Reference 3 was provided to the NRC prior to the meeting to outline the BWRVIP requests for clarification. The NRC provided clarifications allowing the BWRVIP to proceed with providing a response to the BWRVIP-315 draft SE.

To facilitate the NRC staff's review of the BWRVIP's comments, the NRC requested the BWRVIP provide a marked-up copy of the draft SE showing proposed changes and a summary table of the proposed changes. Attachment 1 provides the marked-up copy of the draft SE. Attachment 1 also contains the BWRVIP's comments along with a summary table. Attachment 2 provides the BWRVIP response regarding disposition of the open item included in the BWRVIP-315 draft SE for BWRVIP-315.

The BWRVIP identified that information contained in Attachment 1 includes proprietary information. Therefore, Attachment 1 is considered EPRI "Trade Secrets" in accordance with 10CFR2.390. All proprietary information was taken from either BWRVIP-315 or the BWRVIP's responses to NRC Requests for Additional Information (RAI) for the BWRVIP-315 review that was already identified as being proprietary information, along with the requisite affidavits, when those documents were transmitted to the NRC (see References 4 and 5). The requests for withholding were approved by the NRC as documented in References 6 and 7.

If you have any questions regarding this subject, please contact Wynter McGruder at EPRI by telephone at 704.595.2205 or by e-mail at wmcgruder@epri.com.

Sincerely,

Nathan Palm, EPRI, BWRVIP Program Manager
Tim Hanley, Exelon, BWRVIP Chairman

c: BWRVIP Technical Chairs
BWRVIP EPRI Task Managers

Attachment 2

BWRVIP Response to BWRVIP-315 Draft Safety Evaluation Open Item

1. Background

The stated objectives of BWRVIP-315 (provided in Section 1.2 of BWRVIP-315) are as follows:

- Provide a technical basis demonstrating the adequacy of the BWRVIP reactor internals AMP to adequately manage age-related degradation of BWR reactor internals for operation beyond 60 years.
- Document the set of enhancements to BWRVIP reactor internals aging management guidance determined to be appropriate for operation beyond 60 years.
- Define the engineering input limitations relevant to BWRVIP guidance for managing aging of BWR reactor internals, so that program guidance can be applied to any operating period.

In submitting BWRVIP-315, it is the BWRVIP's intent to obtain NRC concurrence that BWRVIP guidance, with the guidance enhancements and revisions proposed in Appendix B of BWRVIP-315, represent an acceptable method for managing aging of BWR reactor internals for extended operations (operation beyond 60 years with no fixed service life limitation).

A recently identified 10 CFR Part 21 issue related to a non-conservatism in BWRVIP guidance for irradiated stainless steel weld metal fracture toughness [1], [2], [3] caused NRC staff reviewing BWRVIP-315 to question if the conclusions reached in BWRVIP-315 are impacted and resulted in an open item being included within the draft SE for BWRVIP-315. This open item response addresses the specific issues raised within the open item and also documents the results of a comprehensive review of the issue.

Section 2 of this attachment summarizes the identified non-conservatism in BWRVIP-100, Rev. 1-A [4] and the associated BWRVIP-315 draft SE open item. Section 3 provides the BWRVIP's evaluation of the specific issues identified by the staff in the open item. Section 4 summarizes a BWRVIP evaluation of the reactor internals potentially affected by the non-conservatism. Section 5 provides a summary of the BWRVIP perspective regarding risk associated with the non-conservatism. Section 6 provides markups of content in BWRVIP-315 that the BWRVIP believes are appropriate in response to the non-conservatism in BWRVIP-100, Rev. 1-A. This new and modified content will be included in the NRC approved version of BWRVIP-315.

As a result of this review, the BWRVIP maintains that this non-conservatism does not represent a challenge to the adequacy of the BWRVIP reactor internals aging management program for extended operations and that BWRVIP-315, with modifications as proposed in Section 6 of this document, remains an appropriate basis for aging management of BWR reactor internals during extended operations.

2. Scope and Applicability of the Non-Conservatism

The BWRVIP-100, Rev. 1-A non-conservatism is summarized as follows in an EPRI 10 CFR Part 21 notification letter dated Feb. 19, 2021 [1]:

"BWRVIP-100, Rev. 1-A, published in 2016, was developed to support the evaluation of in-service flaws in BWR core shrouds. It provides fracture toughness relationships as a function of neutron fluence for BWR core shrouds. Research was carried out from 2016 to 2020 to obtain additional fracture toughness data on irradiated stainless steels with an emphasis on weld metal. A preliminary evaluation of results from this testing program, as well as the results of other applicable testing programs, indicates that the relationships published in BWRVIP-100, Rev. 1-A are nonconservative in the fluence range from 5E20 n/cm² to 3E21 n/cm² when considering the newly acquired weld metal data. Specifically, the lower bound fracture toughness of 50 ksi-in½ specified in BWRVIP-100, Revision 1-A may be reached at a fluence of 5E20 n/cm² as opposed to the previously defined threshold of 3E21 n/cm².

[1] Prior evaluations of fracture toughness data published in BWRVIP-100 did not distinguish between base metal, HAZ and weld, and were considered to be appropriately conservative."

The potential non-conservatism is limited to observations of weld metal fracture toughness test results below the BWRVIP-100, Rev. 1-A threshold values for fluences between 5×10^{20} n/cm² and 3×10^{21} n/cm². As a result, the impact of this potential non-conservatism on BWRVIP aging management guidance for reactor internals is limited to guidance addressing structural evaluation of flaws identified in weld zones meeting both of the following criteria:

(1) The guidance must address structural evaluation of identified flaws that have tips located in, adjacent to, or very close to a structural weld having a safety function.

Note: *IGSCC initiation and growth in stainless steel reactor internals occurs almost exclusively within weld HAZ material, not weld metal. Based on the current state of knowledge, the BWRVIP conservatively considers any IGSCC located in the weld HAZ and having flaw tips largely parallel to the weld direction to have the potential for unstable extension into and through the weld itself when subject to design basis loads. Flaws identified in welds whose function is redundant or in welds not having a structural integrity function (e.g., anti-rotation tack welds) do not require structural evaluation and are not affected by the non-conservatism.*

(2) The potential for structural evaluations to have an end-of-interval[1] neutron fluence between $5x10^{20}$ n/cm^2 and $3x10^{21}$ n/cm^2 must exist.

Note: *Structural evaluations of flaws associated with welds that have end-of-interval fluences either above or below this range are unaffected. Many reactor internals will never approach a fluence of $5x10^{20}$ n/cm^2. A limited set of welds are already above $3x10^{21}$ n/cm^2. Flaw evaluation guidance for these cases is not affected and is not an extended operations concern since the evaluations must use the lower fracture toughness value from BWRVIP-100, Rev. 1-A (50 ksi-in^{½}). Therefore, the set of applicable component locations is limited.*

3. Evaluation of the BWRVIP-315 Draft Safety Evaluation Open Item

3.1 Content of Open Item

Section 4.17.2 of the draft SE for BWRVIP-315 summarizes the staff concern and associated open item:

"At a May 27, 2021, public meeting, the BWRVIP described additional fracture toughness data that impacts the inspection and evaluation recommendations in BWRVIP-100, Revision 1-A. The BWRVIP-100, Revision 1-A, recommendations impacted the inspection and evaluation guidance in BWRVIP-76, Revision 1-A, which is relied on in BWRVIP-315. The new fracture toughness data indicated that brittle fracture may become the dominant failure mode at an earlier fluence than currently identified in BWRVIP-100, Revision 1-A, and BWRVIP-76, Revision 1-A. The new fracture toughness data may also impact the toughness characterization for the ductile fracture failure mode.

Furthermore, the BWRVIP-315 TR references BWRVIP-100, Revision 1-A, fluence thresholds and material properties, as summarized below.

- *Sections 3.3.2.2 and E.4.9 of BWRVIP-315 reference irradiation embrittlement threshold of $1x10^{21}$ n/cm^2. The new toughness data described in the May 27, 2021, public meeting suggests that $5x10^{20}$ n/cm^2 is a more appropriate threshold.*
- *Section 4.2.3.2 of BWRVIP-315 states that licensees may reference the yield strength data when applying Code Case N-889 to determine IASCC crack growth rate.*
- *Sections 4.3.18.3, 4.3.19.3, B.2.1, and B.4 of BWRVIP-315 state that BWRVIP-100, Revision 1-A, fracture toughness values may be used as inputs in flaw evaluations for reactor internals components.*

[1] The service time permitted until a weld needs to be reinspected based on either on generic acceptance criteria or on a plant specific evaluation.

"...Since new data is available that calls into question certain fluence thresholds and material properties referenced in BWRVIP-315, the NRC staff finds that disposition of the BWRVIP-100, Revision 1-A, nonconservatism is an open item for the NRC staff review of BWRVIP-315 TR."

3.2 BWRVIP Evaluation

In the first paragraph of the open item, the staff concludes that core shroud inspection and flaw evaluation guidance are impacted by the BWRVIP-100, Rev. 1-A non-conservatism. Although data review and development of revised guidance for failure modes and fracture toughness of irradiated stainless steels is not yet complete, the BWRVIP agrees that core shroud aging management guidance is likely impacted by the non-conservatism. As an interim step until data evaluation and development of revised guidance is completed, the BWRVIP has issued a set of conservative recommendations to members to address the non-conservatism, including a recommendation that plants evaluate their use of BWRVIP-100, Rev. 1-A as an input to flaw evaluations to determine if any flaw evaluations could be impacted, possibly resulting in either a reduction in structural margins or a change in inspection frequency. This recommendation applies specifically to flaw evaluations associated with reactor internals having accumulated fluence in the range of $5x10^{20}$ n/cm^2 to $3x10^{21}$ n/cm^2 at the end of the evaluation interval [2].

Since this issue is being managed through a set of interim recommendations issued in response to the 10 CFR Part 21 notification and revised guidance will be issued well before any BWR operates in a second license renewal period, the BWRVIP maintains that the identified non-conservatism does not represent a challenge to the capability of BWRVIP guidance to adequately manage aging of reactor internals for extended operations. Further, there is no change to guidance for evaluation of flaws in highly irradiated weld regions with fluence exceeding $3x10^{21}$ n/cm^2. Although some flaw evaluations associated with fluences between $5x10^{20}$ n/cm^2 and $3x10^{21}$ n/cm^2 are impacted, the interim recommendations provided by the BWRVIP conservatively address the identified fracture toughness non-conservatism until revised guidance is issued. As a result of the 10 CFR Part 21 notification, licensees will update structural evaluations of flaws and adjust inspection periodicity accordingly. In terms of assessing overall program adequacy, this occurrence provides a clear example of the proactive nature of the BWRVIP program as implemented under the NEI 03-08 materials initiative.

In the first bullet within the open item, the staff notes that BWRVIP-315 Section 3.3.2.2 includes a $1x10^{21}$ n/cm^2 threshold for consideration of irradiation embrittlement and questions if that threshold remains appropriate given the BWRVIP-100, Rev. 1-A non-conservatism. In this specific case, the BWRVIP maintains the $1x10^{21}$ n/cm^2 threshold fluence is not affected by the non-conservatism because the specific section referenced by the staff (Section 3.3.2.2) is applicable only to stainless steel fasteners, not welded assemblies. This bullet also identifies a reference to BWRVIP-100, Rev. 1-A in Appendix E, Section E.4.9. The BWRVIP agrees that this content is affected by the non-conservatism. The BWRVIP proposes to address this portion of the open item by removing this sentence from the NRC-approved version of BWRVIP-315 (see Section 6 of this document).

In the second bullet within the open item, the staff notes that ASME Code Case N-889 includes yield strength as an input to the determination of an appropriate crack growth rate (CGR). The BWRVIP interprets the context of this bullet item to imply that the staff is concerned about the applicability of the ASME Code Case N-889 CGR correlation given the recent data suggesting that a significant reduction in stainless steel weld metal fracture toughness occurs at a lower fluence than in stainless steel base metal and, by association, that the yield stress model used by ASME Code Case N-889 could also be impacted. The BWRVIP maintains that the BWRVIP-100, Rev. 1-A non-conservatism is not relevant to CGR correlations included in Code Case N-889 for several reasons: First and of primary importance, IGSCC in stainless steel materials occurs almost exclusively within weld HAZ material, not weld metal. The non-conservatism is applicable only to unstable extension of cracks subject to loads imposed by accident or upset conditions and only then because the BWRVIP has chosen to conservatively assume flaw tips will be sufficiently close to the weld that weld metal material properties are applicable. For the purpose of assessing stable, subcritical flaw growth due to IGSCC, HAZ and base material properties are appropriate. Second, the ASME Code Case N-889 CGR correlation includes consideration of not only increases in yield strength occurring due to irradiation, but also pre-irradiation increases associated with fabrication effects. At low fluences, the pre-irradiation increase in yield strength due to weld shrinkage has a more significant effect on the estimated CGR than the increase in yield strength due to irradiation. Finally, when compared with field inspection data, the CGR predictions from ASME Code Case N-889 are without exception very conservative.

In the third bullet within the open item, the staff identifies several sections within BWRVIP-315 that refer to flaw evaluation inputs for irradiated stainless steel CGRs and fracture toughness. The BWRVIP agrees that once a final evaluation of available fracture toughness data is complete, that a revision to BWRVIP-100 will likely be necessary. However, the BWRVIP maintains that final disposition of this issue in a revision of BWRVIP-100 is not necessary for staff evaluation of the adequacy of the BWRVIP program for reactor internals to address extended operations for the following reasons:

- The BWRVIP has already provided conservative recommendations to members that a lower bound fracture toughness value of 50 ksi-inch½ consistent with weld metal properties be used to re-evaluate structural integrity assessments involving irradiated stainless steel welded structures with accumulated fluence between $5x10^{20}$ n/cm² and $3x10^{21}$ n/cm² [2]. This interim set of recommendations is based on a very conservative interpretation of the available materials property data, addresses the non-conservatism comprehensively, and is applicable to any operating time frame.
- The non-conservatism does not represent a new "unknown" condition or materials property knowledge gap resulting from consideration of extended operations. Evaluation methods for fluence values greater than $3x10^{21}$ n/cm² are unchanged. For plants operating beyond 60 years, highly irradiated components (e.g., core shroud beltline welds and top guide welds) will have accumulated fluence greater than $3x10^{21}$ n/cm² well before 60 years of operation. As a result, extended operations aging management for these components is not affected in any way.

Therefore, there is no effect of the non-conservatism on the adequacy of BWRVIP aging management guidance to address extended operations since the BWRVIP has already provided interim recommendations that fully address the issue and existing materials property data and evaluation methods for fluences exceeding $3x10^{21}$ n/cm² are unchanged. Nonetheless, to ensure that all potential impacts have been considered, the BWRVIP performed a comprehensive review of reactor internals aging management guidance. Section 4 of this report contains a summary of this evaluation. Finally, the BWRVIP recognizes that changes to

BWRVIP-315 are appropriate to ensure that the staff has confidence the non-conservatism will be addressed by revisions to BWRVIP guidance. As such, a list of proposed revisions that will be made in the NRC-approved version of BWRVIP-315 are listed in Section 6 of this document.

4. Affected Reactor Internals Aging Management Guidance

Within reference [1], a recommendation is made that structural evaluations of flaws associated with components having accumulated fluence in the range of $5x10^{20}$ n/cm^2 to $3x10^{21}$ n/cm^2 be reviewed for potential impact. BWRVIP-315, Appendix E provides a basis for identifying the set of reactor internals that may be impacted. Reactor internals using stainless steel welded construction and exposed to neutron flux sufficient for some portion of the assembly to accumulate fluence approaching $5x10^{20}$ n/cm^2 are as follows:

Core Plate Welded Assembly:
Core plate aging management is not affected. Core plate intended function is maintained so long as the holddown bolts are intact or wedges, if installed, remain in place. Structural evaluation of welds is not required.

CRGTs:
Guidance for structural evaluation of welds located at the upper end of the CRGT should be updated to ensure the effects of fluence are appropriately considered. This revision to the I&E guideline addressing CRGTs (BWRVIP-47-A) is already identified as a needed revision in BWRVIP-315, Section 4.5.2, "BWRVIP Guidance Revisions" and the revised guidance is included in BWRVIP-315, Appendix B. Section 6 of this document includes proposed BWRVIP-315 content revision to clarify that plants should use the current guidance approved by the BWRVIP related to fracture toughness (or other analysis input parameters) when performing structural evaluations.

Jet Pumps:
The currently applicable I&E guideline for jet pumps (BWRVIP-41, Rev. 4-A) includes guidance to ensure that the effects of fluence are appropriately considered. Two options for addressing fluence effects in structural evaluations are provided. The first approach involves taking no credit for material exposed to fluence exceeding $3x10^{20}$ n/cm^2. This approach does not rely on irradiated material properties and is not impacted by the non-conservatism. Alternatively, the evaluation may be performed using methodologies analogous to those for core shrouds in BWRVIP-76. In this case, content had already been added to BWRVIP-41, Rev. 4-A to address irradiation effects on structural evaluations prior to completion of BWRVIP-315. However, to ensure that the BWRVIP-100, Rev. 1-A non-conservatism is appropriately addressed in BWRVIP-41, Rev. 4-A, content modifications are proposed in Section 6 of this document. These changes will be added to the NRC-approved version of BWRVIP-315 and ultimately incorporated into a future version of BWRVIP-41.

LPCI Couplings:
Guidance for structural evaluation of welds should be updated to ensure the effects of fluence are appropriately considered. A revision to the I&E guideline addressing LPCI couplings (BWRVIP-42, Rev. 1-A) for this purpose is already identified as a needed revision to address extended operations in BWRVIP-315, Section 4.5.2, "BWRVIP Guidance Revisions". Section 6 of this document includes proposed BWRVIP-315 content revision to clarify that plants should use the current guidance approved by the BWRVIP related to fracture toughness (or other analysis input parameters) when performing structural evaluations.

Core Shroud:
Aging management of core shroud welds is directly addressed by the EPRI BWRVIP Part 21 notification regarding the BWRVIP-100, Rev. 1-A non-conservatism. However, no changes to the content in BWRVIP-315 are needed other than the addition of footnotes to communicate the interim status of core shroud guidance and impending need to revise BWRVIP-76 once a revised version of BWRVIP-100 is completed.

Top Guide Rim and Support Assembly:
Guidance for structural evaluation of cracking in the rim and support assembly should be updated to ensure the effects of fluence are appropriately considered. Revision to the I&E guideline addressing top guide rim and support structure (BWRVIP-26-A) is already identified as a needed revision to address extended operations in BWRVIP-315, Section 4.5.2, "BWRVIP Guidance Revisions". Appendix B of BWRVIP-315 provides a general description of content modifications to be made to BWRVIP-26. No changes to BWRVIP-315 are needed.

Top Guide Grid Beams:
Grid beam aging management is not affected. BWR/3-5 grid beam assemblies are comprised of interlocking plates and do not contain welds. BWR/6 grid assemblies are fabricated from two or three plates welded together and with the grid squares produced by machining. Although the BWR/6 grid structure does contain welds, IGSCC occurring along the length of a weld has no effect on top guide function since, even with complete cracking, the plate sections would be adequately supported by the perimeter bolting. Cracking that bi-sects a weld is not judged to be plausible. Further, for most cases, the non-conservatism will not be applicable to structural evaluation of a top guide grid beam because the non-conservatism is applicable only to structural evaluations in the fluence range of $5x10^{20}$ to $3x10^{21}$ n/cm^2. Top guide grid beam fluence will be higher than $3x10^{21}$ n/cm^2 for most plants, in a range where a fracture toughness value of 50 ksi-in$^{1/2}$ is applicable, for both base metal and weld metal. No changes to BWRVIP-315 are needed.

5. Consideration of Risk

In a November 17, 2021 transmittal [5], the staff documented a technical evaluation of the non-conservatism in BWRVIP-100, Rev. 1-A. Key staff conclusions from this assessment are that critical lengths for through-wall flaws in core shroud welds are long (18% or more of the length of a core shroud circumferential weld) and that the probability of a flaw exceeding this length is very small.

During 2021, the BWRVIP undertook a rigorous probabilistic evaluation of core shroud integrity, including detailed evaluation of the impact of the BWRVIP-100, Rev. 1-A non-conservatism. Key observations from this work are that core shroud failure due to brittle fracture occurs only with thru-wall circumferential flaws having significant length, a similar conclusion to that obtained by the staff in its evaluation. Additional key observations from the BWRVIP work include:

(1) Essentially all shroud failure cases involve brittle failure in the presence of through-wall cracks. Shroud failure is highly improbable when only part through-wall cracks exist.

(2) Due to the typical weld residual stress profile of a core shroud horizontal weld, cracks are very unlikely to grow through-wall by IGSCC. This analytically predicted result documented in BWRVIP-14-A [6] is supported by the BWRVIP's extensive collection and evaluation of core shroud field inspection data. In a dataset including several thousand core shroud circumferential weld indications, there are none that validated to be thru-wall and most cracks have a depth that is substantially less than 50% of the shroud thickness. Thus, the probability that a long thru-wall crack will develop in a core shroud horizontal weld is very low.

(3) Due to the implementation of effective HWC throughout the U.S. fleet, growth of IGSCC cracks in core shroud welds remains very low and is difficult to distinguish from NDE uncertainty.

Based on these observations, it can be concluded that the probability of through-wall cracks developing in core shroud horizontal welds is extremely low, even when considering extended operations. In contrast, the staff evaluation effectively assumes the probability of a though-wall crack to be 1.0 since only through-wall cracking cases were considered. This is a significant conservatism included in the staff's evaluation that further supports the determination that the identified non-conservatism is not risk significant.

Finally, the staff notes in its evaluation, and the BWRVIP agrees, that core shroud failure due to degraded conditions can only potentially occur as result of loads from LOCAs or seismic events. Normal operating loads are insignificant for core shroud integrity. As such, for core shroud failure to occur, both a significantly degraded condition undetected by periodic inspection AND an initiating event such as a seismic event must be postulated. Given that plants continue to periodically inspect high fluence core shroud welds and that use of weld metal fracture toughness to assess flaw stability is recommended, the BWRVIP concludes that there is no significant change in risk resulting from the BWRVIP-100, Rev. 1-A non-conservatism.

6. Changes Proposed for the NRC-Approved Version of BWRVIP-315

The following revisions to BWRVIP-315 are proposed as a means of addressing the BWRVIP-100, Rev. 1-A non-conservatism. These proposed changes will be added in the NRC-approved version of BWRVIP-315 (BWRVIP-315-A).

A note will be added to the end of Section 1 to clarify the intent associated with citation of specific versions of BWRVIP guidance:

References to BWRVIP guidance documents that specify specific versions (either revision numbers, "-A" to indicate NRC-approval, or both) within this report reflect the version of the guidance approved at the time BWRVIP-315 was developed. This was done out of convenience for the purpose of demonstrating that the BWRVIP program for reactor internals as currently structured (and with revisions as indicated in Appendix B of this report to eliminate time-dependencies) remains adequate for operation beyond 60 years. As new versions of BWRVIP guidance are approved by the BWRVIP for use, those new versions supersede the versions listed in this report. All newly developed BWRVIP guidance is intended to be applicable for any operating time, up to and exceeding 80 years. There is no intention that plants operating beyond 60 years can use this report as a basis for implementing BWRVIP guidance that has been superseded by new and improved guidance.

A footnote will be added to citations of BWRVIP-100, Rev. 1-A:

At the time of completion of BWRVIP-315-A, work was in progress to address a non-conservatism affecting the conclusions of BWRVIP-100, Rev. 1-A. Alternate guidance to be used in the interim period until a revision of BWRVIP-100, Rev. 1-A is completed is provided within an EPRI letter addressing the 10 CFR 21 issue: Update Regarding 10 CFR Part 21 Transfer of Information Notice – Potential Non-Conservatism in EPRI Software (BWRVIP-235) and Inspection and Evaluation Guidance for the BWR Core Shroud (BWRVIP-76 Revision 1-A, BWRVIP-76 Revision 2, and BWRVIP letter 2016-030), March 19, 2021.

A footnote will be added to citations of BWRVIP-76 and BWRVIP letter 2016-030:

At the time of completion of BWRVIP-315-A, work was in progress to address a non-conservatism affecting the conclusions of BWRVIP-76 and BWRVIP interim guidance 2016-030. Alternate guidance to be used in the interim period until revisions to these guidance documents is completed is provided within an EPRI letter addressing the 10 CFR 21 issue: Update Regarding 10 CFR Part 21 Transfer of Information Notice – Potential Non-Conservatism in EPRI Software (BWRVIP-235) and Inspection and Evaluation Guidance for the BWR Core Shroud (BWRVIP-76 Revision 1-A, BWRVIP-76 Revision 2, and BWRVIP letter 2016-030).

Section 3.3.2.1, Stainless Steel Structures, will be modified as follows (deletions in ~~strikethrough~~, additions in **bold**):

> *Based on data from control blade sheath cracking, for austenitic stainless steels, the nominal "threshold" irradiation value for IASCC applied in this report is $5x10^{20}$ n/cm^2 (E > 1.0 MeV) [3-17], [3-3]. Although this threshold is in practice considered to be conservative, it is reasonable for application as a screening value. A practical factor associated with this neutron fluence threshold is that BWRVIP guidance specifies use of a different crack growth rate (CGR) for stainless steels subject to fluence exceeding $5x10^{20}$ n/cm^2 (E > 1.0 MeV) [3-18], [3-19]. With regard to consideration of the impact of irradiation embrittlement on component performance, the only significant effect is a reduction in fracture toughness that must be considered in flaw tolerance evaluations.* ***Available data indicate*** *~~BWRVIP-100, Rev. 1-A [3-20] specifies~~ use of reduced fracture toughness values* ***may be appropriate at*** *~~for~~ fluences* ***as low as $5x10^{20}$ n/cm^2*** *~~1x1021 n/cm2 (E > 1.0 MeV)~~. Therefore, this ~~the lower of these two~~ values is selected for screening of IASCC / Irradiation Embrittlement.*

Section 3.3.2.2, SA SS and XM-19 Threaded Fasteners, the last section of the first para. and the 2nd bullet item will be modified as follows (additions in **bold**):

> *Regardless, to ensure a conservative approach is taken regarding screening for impacts to aging management guidance, the value of $1x10^{21}$ n/cm^2 (E > 1.0 MeV) from BWRVIP-100, Rev. 1-A* ***for stainless steel base material*** *is considered reasonable. The following screening criteria result:*
>
> - *For threaded fasteners exposed to low ECP conditions (MHWC / NMCA / OLNC), the threshold for consideration of reduced fracture toughness from BWRVIP-100, Rev. 1-A* ***for stainless steel base material*** *is used, $1x10^{21}$ n/cm^2 (E > 1.0 MeV).*

A new Section B.1.4 will be added to address changes needed to BWRVIP-41, Rev. 4-A, Section 5.1.2.2 to address the BWRVIP-100, Rev. 1-A non-conservatism:

> *5.1.2.2 Effects of Irradiation*
>
> *IGSCC flaw evaluations for welds shall account for the effects of irradiation if a plant-specific assessment indicates that the end-of-interval (EOI) fluence may exceed $3x10^{20}$ n/cm^2 for any portion of the weld being evaluated. One evaluation approach that may be used is to perform a limit load analysis assuming that the length of the weld exceeding $3x10^{20}$ n/cm^2 at EOI is removed from the weld. Alternatively, the weld may be evaluated using limit load analysis and either linear-elastic fracture mechanics or elastic-plastic fracture mechanics techniques. These approaches to evaluating high fluence welds are described in additional detail in* ***the current version of BWRVIP-76 approved by the BWRVIP*** *~~Appendix D of BWRVIP-76, Revision 2~~.*

Section B.2.1, Subsection describing new content to be added to BWRVIP-42 to address the effects of irradiation on LPCI coupling structural evaluations will be modified as follows (deletions in ~~strikethrough~~, additions in **bold**):

5.1.2.2 Effects of Irradiation

IGSCC flaw evaluations for welds should account for the effects of irradiation if assessment indicates that the end of interval fluence may exceed 3x10^{20} n/cm^{2} (E > 1.0 MeV) for any portion of the weld being evaluated. The effects of neutron fluence on failure mode, fracture toughness, and crack growth rate should be considered and addressed in a manner consistent with the guidance given in ***current guidance approved by*** *the ~~existing~~ BWRVIP ~~documents such as BWRVIP-14-A, BWRVIP-59-A, BWRVIP-99-A, and BWRVIP-100, Rev. 1-A~~. One evaluation approach that may be used is to perform limit load analysis assuming that the length of weld exceeding 3x10^{20} n/cm^{2} (E > 1.0 MeV) at EOI is removed from the weld. These approaches to evaluating high fluence welds are described in additional detail in* ***the current version of BWRVIP-76 approved by the BWRVIP*** *~~Appendix D of BWRVIP-76, Revision 1-A~~.*

Section B.3.2, Subsection describing modified content in Section 5.3 of BWRVIP-47-A will be modified as follows (deletions in ~~strikethrough~~, additions in **bold**):

...Alternative methods may be used if they can be technically justified. The effects of neutron fluence on failure mode, fracture toughness, and crack growth rate should be considered and addressed in a manner consistent with the guidance given in the ***current version of BWRVIP-76 approved*** *~~existing~~* ***by the*** *BWRVIP ~~documents such as BWRVIP-14-A, BWRVIP-59-A, BWRVIP-99-A, and BWRVIP-100, Rev. 1-A~~.*

Section E.4.9, Top Guide will be modified as follows (deletions shown in ~~strikethrough~~):

Table E-13 provides 80-year fluence estimates for the top guide. The rim structure fluence is estimated as the mean of the shroud H2 and H3 welds. This is acknowledged to be an approximation, but is reasonable to establish a general understanding of fluence in this area. Depending on plant design, the 80-year fluence accumulated at the rim support region may exceed the 5x10^{20} n/cm^{2} (E > 1.0 MeV) threshold for IASCC. ~~In some cases, it may also exceed the 1x10^{21} n/cm^{2} (E > 1.0 MeV) threshold specified by BWRVIP-100, Rev. 1-A for assuming a reduction in K_{IC} in fracture mechanics evaluations.~~

7. Conclusions

The BWRVIP concludes that the BWRVIP-100, Rev. 1-A weld metal fracture toughness non-conservatism does not challenge the adequacy of BWRVIP guidance to adequately manage aging of BWR reactor internals for operation beyond 60 years and should not represent a barrier to completion of the staff's review of BWRVIP-315. Key observations and conclusions from the BWRVIP evaluation include:

- The BWRVIP has already provided a set of interim recommendations issued in response to the 10 CFR Part 21 notification. These recommendations comprehensively address the impact of the BWRVIP-100, Rev. 1-A potential non-conservatism and are applicable to any licensed operating period.
- The non-conservatism does not represent a new knowledge gap associated with operation beyond 60 years. Applicability is limited to an intermediate fluence range and as such structural evaluations of flaws in highly irradiated reactor internals are not impacted by consideration of extended operations.
- The non-conservatism is applicable only to unstable extension of cracks subject to loads imposed by accident or upset conditions and only because the BWRVIP has chosen to conservatively assume that flaw tips are sufficiently close to the weld that weld metal material properties are applicable. For the purpose of assessing stable, subcritical flaw growth due to IGSCC, use of HAZ and base material properties remains appropriate. Therefore, CGR correlations for IGSCC occurring in irradiated stainless steel reactor internals are unaffected.
- The non-conservatism has limited practical applicability to reactor internals aging management:
    - Flaws identified in welds whose function is redundant or in welds not having a structural integrity function (e.g., anti-rotation tack welds) do not require structural evaluation and are not affected by the non-conservatism.
    - Affected reactor internals are limited to those exposed to fluence in the range of $5x10^{20}$ to $3x10^{21}$ n/cm^2. Many reactor internals will never approach this fluence. For those reactor internals subject to neutron fluence in the range of interest, noble metal catalyzed HWC provides effective IGSCC mitigation.
- The non-conservatism has a minimal impact on overall plant risk since for core shroud failure to occur, both a significantly degraded condition undetected by periodic inspection AND an initiating event such as a seismic event must be postulated. Given that plants continue to periodically inspect high fluence core shroud welds and that use of weld metal fracture toughness is recommended in assessments of flaw stability, the BWRVIP concludes that there is no significant change in risk resulting from the BWRVIP-100, Rev. 1-A non-conservatism.
- Section 6 of this document provides details of the changes proposed to BWRVIP-315 to address the BWRVIP-100, Rev. 1-A non-conservatism.

8. References

[1] EPRI Letter, "10 CFR Part 21 – Transfer of Information Notice – Potential Non-Conservatism in EPRI Software, BWRVIP-235, 1018251," February 19, 2021.

[2] EPRI Letter, "Update Regarding 10 CFR Part 21 Transfer of Information Notice – Potential Non-Conservatism in EPRI Software (BWRVIP-235) and Inspection and Evaluation Guidance for the BWR Core Shroud (BWRVIP-76d, Rev. 1-A, BWRVIP-76, Rev. 2, and BWRVIP letter 2016-030).

[3] BWRVIP letter 2021-030, Potential Non-Conservatism in EPRI Report, BWRVIP-100, Rev. 1-A, 3002008388 and Impacted BWRVIP Reports, EPRI (Palm) to U.S. NRC (Gonzalez).

[4] *BWRVIP-100, Rev. 1-A, BWR Vessel and Internals Project, Updated Assessment of the Fracture Toughness of Irradiated Stainless Steel for BWR Core Shrouds*, EPRI, Palo Alto, CA: 2016: 3002008388.

[5] Technical Assessment of Nonconservative Fracture Toughness in Boiling Water Reactor Vessel and Internals Project Topical Report BWRVIP-100, Revision 1-A, U.S. NRC, Nov. 17, 2021.

[6] *BWRVIP-14-A, BWR Vessel and Internals Project, Evaluation of Crack Growth in BWR Stainless Steel RPV Internals*, EPRI, Palo Alto, CA: 1996. TR-105873.